Science and Technology in Italy

For the upgraded ALMA Observatory

- TECHNOLOGY DEVELOPMENT -

Development Plan Study for Optimization and Production Engineering of Band 2+3 Prototype Components for ALMA Receivers

INAF Mid Term Report

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1 Change Record

Version	Date	Affected sections	Reason
A	09/07/2019	All	First issue for Mid Term Review
B	11/02/2020	Section 6	Sentence rephrased
B	11/02/2020	Par. 7.2.2	Results from the CuTe OMT thermo-elastic analysis has been added (AI#1 MTR meeting)
B	11/02/2020	Par 7.5	WP3 Science case section updated on the basis of mail exchanges. AI#2
B	11/02/2020	Section 8	Deliverables. Section updated with explanation of DS3 results.
B	11/02/2020	Section 2	[RD13] and [RD14] Added
B	11/02/2020	Section 3	Acronyms table updated

2 Applicable and reference Documents

AD 1	Collaboration Agreement No.74288/16/8223/OSZ entitled 'Band 2+3 Prototype Passive Components for ALMA Receiver' for the Development Advanced Study for upgrades of the Atacama Large Millimeter/Submillimeter Array(ALMA).
AD 2	Development Plan Study for Optimization and Production Engineering of Band 2+3 Prototype Components for ALMA Receivers, Statement of Work, FEND-05.00.00.00-0013-A-SOW
AD 3	Advanced Study for Upgrades of ALMA: Optimization and Production Engineering of Band 2+3 Prototype Components for ALMA Receivers Minutes of Meeting May 16th, 2017, FEND-05.00.00.00-0017-A-MIN
AD 4	Optimization and production engineering of Band 2+3 Prototype Components for ALMA receivers Progress Report, iALMA-TEC-PRR-OAS-001, Rev. A, 09/07/2018

RD 1	Feed ALMA Band 2-3 Manufacturing Drawings, iALMA-TEC-DWG-OAA-001, Rev. A, 03/10/2014
RD 2	Flangia inferiore IASF, iALMA-TEC-DWG-OAA-002, Rev. A, 24/07/2015
RD 3	Corrugated feed horn for Electroformation, iALMA-TEC-DWG-OAS-007, Rev. B
RD 4	Wide Bandwidth Considerations for ALMA Band 2, ALMA memo 605
RD 5	Thermo-elastic analysis of INAF Feed OMT Assembly, iALMA-TEC-TRP-OAS-002 Rev. A, 03/07/2019
RD 6	B23 INAF Front End Test at OAA, iALMA-TEC-TRP-OAA-008, Rev. A, 07/02/2019
RD 7	VNA Measurements of B23 Optics at INAF, iALMA-TEC-TRP-OAA-010 Rev. A, 3/03/2019
RD 8	Circular to Rectangular Waveguide Adapter Flange Modification and CuTeOMT Loss Test, iALMA-TEC-TRP-OAA-009, Rev. A, 27/03/2019

RD 9	CuTe OMT manufacturing Drawings, iALMA-TEC-DWG-OAA-003, Rev. A, 4/7/2018
RD 10	B23 OMTs Progress Status, iALMA-TEC-TRP-OAA-007, Rev. A, 04/07/2018
RD 11	iALMA Passive Components B23 OMT Optimization, iALMA-TEC-TRP-OAA-003, Rev. A, 23/03/2016
RD 12	B2+3 Warm Test Baseplate Interface Control document, iALMA-TEC-ICD-IAB-001-H, 28/10/2015
RD13	layer contact study of INAF CuTe OMT for Band 2 ALMA receiver, iALMA-TEC-RER-OAS-003, Version, 10/02/2020
RD14	ALMA Acronyms and Abbreviations List, ALMA-80.02.00.00-004-A-LIS

3 Acronyms

INAF	Istituto Nazionale di Astrofisica
ESO	European Southern Observatory
OAS	Osservatorio di Astrofisica e Scienza dello Spazio di Bologna
OAA	Osservatorio Astrofisico di Arcetri, Firenze
UdC	Universidad de Chile
UMAN	University of Manchester
LNF	Low Noise Factroy
LNA	Low Noise Amplifier
OMT	Ortho Mode Transudcer
PDR	Preliminary Design Review
CCA	Cold Cartridge Assembly
WP	Work Package

In addition we refer to the general ALMA acronyms list [RD14].

4 Table of content

5 Introduction and Scope

Scope of this document is to report the activity @ INAF in relation to the work of the collaboration agreement No.74288/16/8223/OSZ entitled 'Band 2+3 Prototype Passive Components for ALMA Receiver' for the Development Advanced Study for upgrades of the Atacama Large Millimeter / Submillimeter Array(ALMA). Specifically, this release covers the activities performed in agreement with the Statement of Work [AD2] from Kick-off to up to now and serve as activity report for the Mid Term Review. According with the Sow, the deliverables expected for the Mid Term Review are summarized in Table 1.

Table 1. List of deliverables for the Mid Term Review

Deliverable	Content
DS1	Consolidation CCA PASSIVE Component Interface Control Document
DS2	Manufacturing Report
DS3	Tolerance Analysis
DS4	Thermal Analysis
DS5	Performance Test Report
DS10	Science Case band 2+3 Progress Report

The activities are organized in Work Packages (WP) as reported in the SoW:

- **WP.1.1: Review Process;** Review Process of previous development and prototype including: evaluation and breakdown performance vs requirements in term of: performances, design and interfaces
- **WP.1.2: Criticalities Identification;** Identification of criticalities and recovery actions (e.g. design optimization, technology update, test setup, test methodology)
- **WP.1.3: New Process;** New manufacturing process investigation and implementation
- **WP.1.4: Fabrication, Test and Verification;** Revision of Verification process in term of Planning, Procedures, Setup Implementation and Test. Fabrication of one set passive components: feedhorn, OMT and waveguides, and their testing
- **WP.3.1: B23 case study improvement;** update the B23 science case

6 Kick off meeting and Band 2+3 framework

The Kick off meeting of this agreement has been held on May, 16th 2017. See the minutes of the meeting FEND-05.00.00.00-0017-A-MIN [AD3]. This study has been harmonized with the Band 2+3 PDR, by focusing the phase 1 in the activities to serve the PDR. After PDR, the effort has been also dedicated in the framework of the developments studies within the Band 2+3 consortium and of the Band 2 small project developments. A progress report was delivered to ESO on 09/07/2018 [AD 4].

7 Work Packages Report

Hereafter the activity reports for each WP is reported.

7.1 WP 1.1 - Review Process

The activity of this work package has been conducted within the activities of the B2 development consortium. Interfaces have been agreed (but not yet frozen) within the development of the CCA prototype. Specifically, for INAF prototype the mechanical interface of the OMT output flange was slightly changed w.r.t the one described in RD12 because of the new optimized OMT design, but maintained with the output waveguides in a parallel arrangement. The breakdown of requirement is not yet consolidated at level of CCA. However, the most critical passive components is the OMT because of its non-negligible attenuation that directly impacts the overall CCA noise. A noise budget for CCA has been developed by ESO for which the effects of the OMT attenuation can be evaluated. An OMT that attenuates -0.40 dB will increase the noise temperature from 30K to 32.96K. A reduction of the OMT attenuation from -0.40dB to -0.25 dB, will correspond to a reduction of the overall noise of 1.5K, i.e. from 32.96K to 31.46K.

7.2 WP.1.2: Criticalities Identification

Criticalities have been identified and hereafter reported.

7.2.1 Feed horn

Two different manufacturing technologies have been studied and compared to each other in terms of performance:

- Aluminium with platelet technology
- Copper with electroforming technology

We fabricated in electroforming copper a feed having mechanical interfaces and Electromagnetic design identical to the platelet one. Then we compared the performances of the two horns. The result was that performance are similar with a small degradation of the return loss in the lower part of the band affecting the electroforming unit as shown in Figure 2.

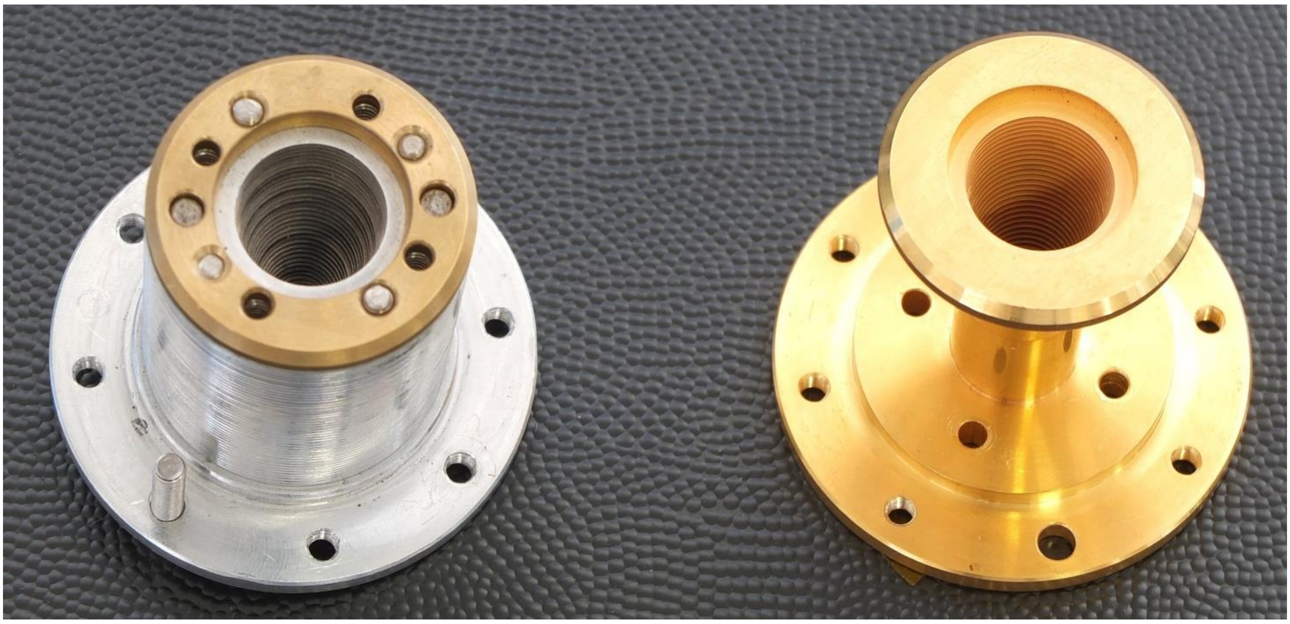

Figure 1. the two prototypes of feed horn. The horn on the left is manufactured in aluminium using platelet technique. The horn on the right is fabricated in copper by electro-formation process.

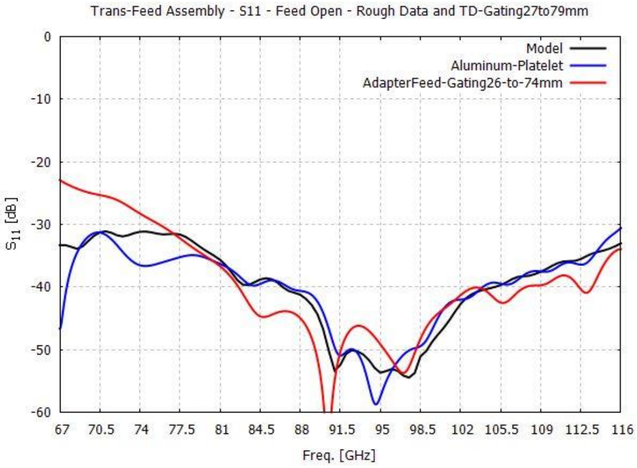

Figure 2. Comparison of Return loss curves from aluminium platelet feed (blue) and electroformed feed (red). The model is also shown in black.

For electroforming, two potential providers were contacted: Custom Microwave Inc. (US) and Thomas Keating Ltd (UK). Custom microwave answered that they were unable to manufacture a horn with such stringent corrugations dimensions, as for the Band 2+3 Horn designed by INAF. Thomas Keating Ltd answered positively and fabricated a unit. No major criticalities have been found in both units. It should be noted that the corrugation profile was critical for electroforming process and this should be taken into account for any future designs. The platelet unit was fabricated by CLOEMA S.c.r.l (IT).

The two mechanical drawings are reported in [RD 1] and [RD 2] for the platelet design and in [RD3] for the electroformed design.

Table 2 reports the main differences between the two different manufacturing techniques.

We experienced long fabrication time (5 months approx.) that could be in principle reduced for production considering the experience of Thomas Keating for ALMA production in other bands. However up to now we believe that the platelet technology for the horn is the most promising way (for INAF design) because of the well-established design-manufacturing-test flow within the commercial collaboration between INAF/OAA and the identified provider (CLOEMA). Moreover, the platelet technology offers the possibility to parallelize the production, manufacturing more than one feed at the same time.

Table 2. differences between fabrication techniques

	Platelet	**Electroformed**
Corrugation profile	able to fabricate any corrugation dimension	Fabrication of tiny corrugations not obvious
Cost of prototype unit	~ 2000 Euros (VAT excluded)	~ 4500 Euros (VAT excluded)
Production	Series production can be optimized to reduce fabrication time by fabricating several units on the same plates in parallel.	Long fabrication time to be taken into account for production planning
Performances	As expected	Slight degradation of return loss (specifically for this unit) but within specs
Cryogenics	Good (but no evidence of criticalities during cool down of CCA)	Optimal because of the use of the Copper and because of the number of mechanical interfaces reduced to just one.
Material	Aluminium	Copper gold plated
Weight	79 gr	85 gr

7.2.2 Orthomode Transducer (OMT)

A revised and optimized design of OMT using CuTe material and a reduced number of plates was made; a prototype basing on this new design was built. Results show an evident improvement of the Insertion Loss, and a degradation of the Return loss: we are confident that the return loss can be improved by further optimizations, not addressed in this study.

A thermo-elastic model of the Feed-OMT assembly was developed at INAF/OAS to study the contraction of the plates at cryogenic temperature for the OMT in brass. The result of the analysis demonstrated that, even at cryogenic temperature, the electrical contact between plates is guaranteed both for feed and OMT. The details of the analysis are reported in [RD 5].

On the contrary, a thermos-elastic analysis has been also performed specifically on CuTe OMT model and reported in [RD13]. The main output is that at cryogenic temperature there is a lack in the contact between the layers that may impact the performance during noise tests. The analysis showed that, from the contact pressure figures, the use of disc spring washer instead of split washer will guarantee the required contact pressure between layers. As the overall conclusion, a revision of the design is not required. The major criticality associated to the OMT is the high insertion loss which is driven by:

- The material used for fabrication
- The interfaces of the OMT impacting on the total electrical path

INAF developed 3 different OMT prototypes units with the goal to reduce the losses:

1. Aluminum OMT
2. Brass OMT
3. Copper Tellurium (CuTe) OMT

The three OMTs were based on three different and optimized design with slightly different interfaces. The latter, based on CuTe, was designed to reduce the noise and to drastically reduce the number of plates from eight to four. The OMT prototype in aluminium has been silver plated. Insertion loss decreased but the plating degraded the cross polarization.

CuTe is certainly the best material with respect to the loss and to the cryogenic performance but it is quite expensive and difficult to procure in Italy in small quantities (for a single prototype). As for Aluminium, brass is a common to find and easy material to manufacture but needs to be plated for vacuum applications. Particular care should be taken during design to guarantee that the plating will not alter the electromagnetic performances.

7.2.3 Waveguides

Two entire set of waveguides for CCA prototypes were manufactured by

- bending commercial WR10 standard Copper tubes
- Copper electroforming WR10 waveguides on Al mandrels.

The two sets were manufactured by *Pasquali Microwave System* in Florence. In both the sets the flanges (made in Brass) were separately manufactured and soldered to the waveguides. No major findings resulted from the manufacturing technique; nevertheless, we found a few issues:

1. loss measured for the electroformed waveguides is higher than for the bent commercial tubes. This can be mitigated by properly specifying the roughness of the aluminum mandrels.
2. electroforming is a slow process: particular attention should be taken for production.
3. In case of complex curves (E-H plane bends) / twists, the manufacturing process of bending commercial tubes may be critical.
4. In case of necessity to gold plating the inner part of the waveguides, the electroforming process is the best, and, depending on the design of the components, the only one.

In addition, for CCA prototype, two straight sections of WR15 stainless steel waveguides were needed and acquired from *Aerowave* (US). We experienced long lead times and poor availability of WR15 stainless steel tube in Europe.

As a conclusion, the best fabrication technology (bending vs electroforming) cannot be identified 'a priori', because it depends on the specific design that will be selected for the production (cost is similar). However, basing on the measured performance, the bending technology seems the most promising one, especially for long bended sections not required to be gold-plated. In case internal gold plating or complicated geometry is required, bending technique is not the best solution due to the difficulty to guarantee uniform gold deposition inside the waveguide tube and difficulty to bend waveguids in different planes. As a conclusion, it is recommended to use beding technique as much as possible, and use other techniques (electroforming) if strictly necessary.

7.3 WP.1.3: New Process

The activity of WP 1.3 has been focused on the optimization and developments of the OMT. As already mentioned a new OMT was fabricated in CuTe and tested. The design resulted from a study to find the best solution in terms of performances, manufacturing and interfaces. The study is reported in [RD 10] in which three new electromagnetic designs were addressed:

1. Design specifically oriented to the electroforming technique
2. Design oriented to the platelet technique, reducing the number of the plates and preserving the parallelism of the output waveguides
3. Design oriented to the platelet technique, reducing the number of the plates and keeping the output waveguides orthogonal to each other.

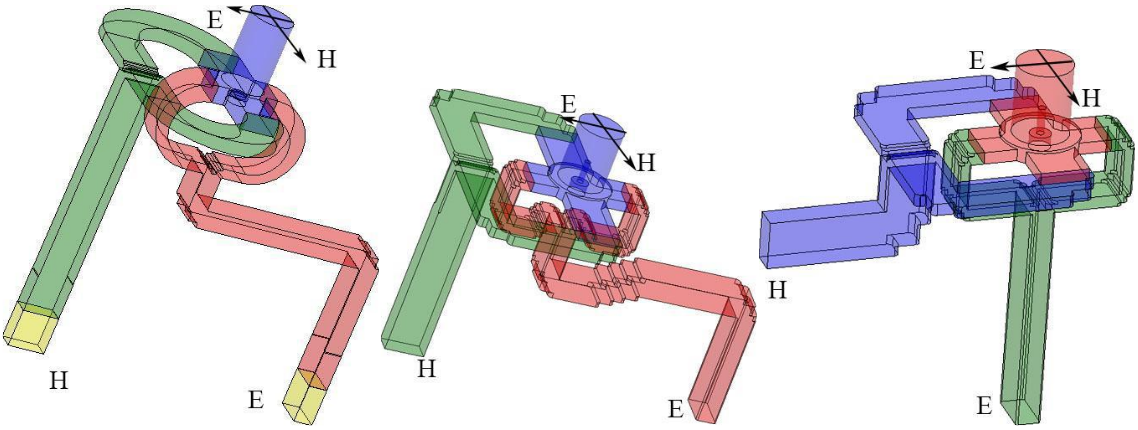

Figure 3. Three different OMT designs performed by INAF/OAA optimized for electroforming (left), reduced number of plates and parallel output (centre), reduced number of plates and orthogonal output (right).

Performances were simulated and the average values are reported in Table 3. It was decided to maintain the output of waveguides in the parallel configuration (less critical for platelet arrangement), whose design permitted to build an OMT with only 4 plates, maintaining compatible interfaces with the current CCA.

Table 3. Average simulated performances of optimized OMTs

Performance	Average over 67-116 GHz
Design for Electro-formation	
Reflections losses	-26.8 dB
Insertion Losses	-0.30 dB
Design with parallel output	
Reflections losses	-24.4 dB
Insertion Losses	-0.32 dB
Design with orthogonal output	
Reflections losses	-24.6 dB
Insertion Losses	-0.24 dB

Figure 4. The new INAF OMT in CuTe under test at INAF/OAA

7.4 WP.1.4: Fabrication, Test and Verification

Within this WP we tested the new OMT in CuTe and the new electroformed horn. Test Report is tracked on [RD 6] In addition, in the framework of band 2 prototype developments, extensive tests have been performed at INAF/OAA using the Vector Network Analyser covering the 67-116 GHz also on OMTs prototypes developed by Universidad de Chile and NAOJ. The measurements are reported in [RD 7].

To permit the test of the Insertion Loss at cryogenic temperatures of the CuTe OMT (at Yebes), the transition originally designed to accommodate the NAOJ OMT in the Yebes facility was modified at INAF/OAA. This modification permitted to test the CuTe INAF OMT at cryogenic temperatures. The design and manufacturing report of the modification is reported in [RD 8].

7.5 WP3 Science Case

The activity of this work package, under the responsibility of INAF/OAA, was concentrated to support the definition of the BAND 2 Science case. Specifically, INAF/OAA (Maite Beltrán) actively participated to the work to issue the ALMA memo dedicated to the extended band 2 (67-116 GHz). The memo is entitled 'Wide Bandwidth Considerations for ALMA Band 2' (ALMA memo 605, see[RD 4] for details). Moreover, on ALMA Cycle 5 INAF/OAA obtained observation time to perform an unbiased spectral line survey over the whole ALMA Band 3 in the framework of the project: "GUAPOS: G31.41+0.31 Unbiased ALMA sPectral Observational Survey" (Principal Investigator Maite Beltrán, INAF/OAA). Observations within the project ALMA2017.1.00501.S has been completed on 2018. A student in INAF/OAA (Chiara Mininni) is reducing data. We started the survey of Band 3 in G31 with the idea of surveying as much bandwidth as possible to identify as many species as possible. The goal is to continue our effort by targeting other bands, and the most wanted in our case is Band 2, because it offers the possibility to study the low-energy transitions of species that not other Band allows. In this sense, the Band 3 (the most suited of all the actual ALMA bands, because it gives a figure of what is expect in Band 2) survey is preparatory for the new Band

2.Specifically, the scan of the Band 3 should complement the study of some species to be carried out with Band 2 (obviously only Band 2). The importance of Band 2, from an astrochemical point of view, is the possibility to detect the ground transitions of some deuterated species. For some species, the hydrogenated version of those species falls in the Band 3. Therefore, to get the deuteration fraction of as many species as possible, it is important to have observations in both bands. Our unbiased spectral survey wants to identify as many species as possible (including complex organic molecules and deuterated species), towards the very chemical rich hot core (G31.41+0.31).

8 Deliverables

In Table 4, we reports the list and the status of deliverables foreseen at Mid Term Review, in agreement with the Statement of Work.

Table 4. list and status of deliverables for Mid Term Review

Deliverable	Content	Status
DS1	Consolidation CCA PASSIVE Component Interface Control Document	See WP 1.1. report (chapter 7.1)
DS2	Manufacturing Report	There is no specific manufacturing report but manufacturing drawings agreed with the manufacturer. See drawings iALMA-TEC-DWG-OAS-007 revision B for feed and iALMA-TEC-DWG-OAA-003 revision A for the CuTe OMT
DS3	Tolerance Analysis	Tolerance analysis was performed on brass OMT (see iALMA-TEC-TRP-OAA-003-A) we did not perform specific tolerance analysis on the CuTe OMT design since we rely on the previous study.
DS4	Thermal Analysis	See document iALMA-TEC-TRP-OAS-002
DS5	Performance Test Report	See documents: iALMA-TEC-TRP-OAA-008, iALMA-TEC-TRP-OAA-010
DS10	Science Case band 2+3 Progress Report	See WP3 update and ALMA Memo 605

Concerning the DS3, the tolerance analysis performed on Electromagnetic model of the brass OMT showed that a typical variation in geometry of 10 microns on the most critical parts of the OMT (i.e. turnstile junction) lead to sensitive variation of the curves but not significant degradation of performance. The Thermo-elastic analysis for the CuTe OMT [RD 13] showed that the typical displacements of the geometry at cryogenic temperature (11K) is 50 microns wich is higher that the tolerance assumed on the manufacturing. This means that, for future, particular care should be given in evaluating performances at cryogenic temperature even if the electrical contact is good.

9 Document Tree

Hereafter in Figure 5 the document tree is reported.

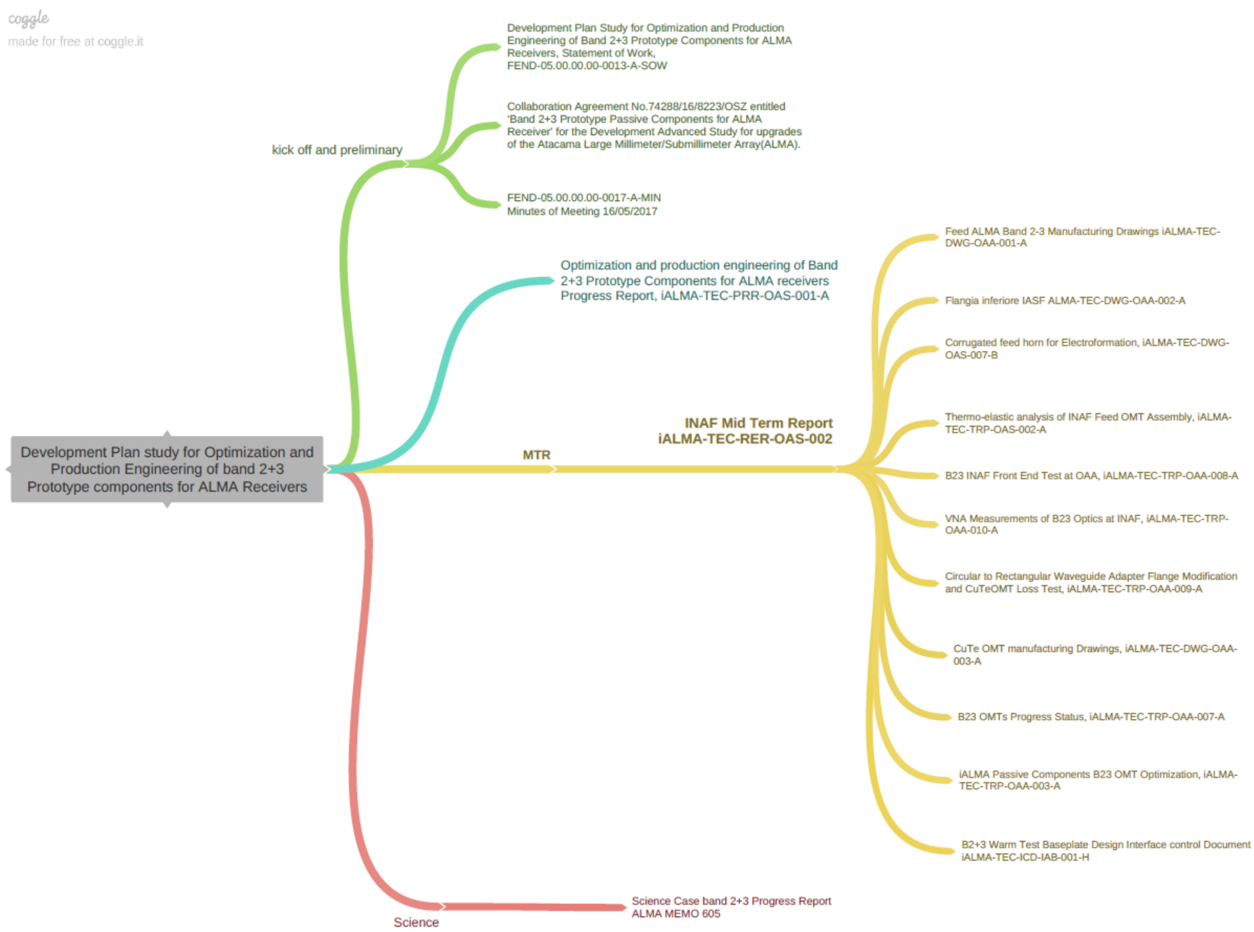

Figure 5. Document tree

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